

AD-A132 364

MEASUREMENT OF FRICTION AND WEAR ON MODIFIED SURFACES

1/

(U) GEO-CENTERS INC NEWTON UPPER FALLS MA AUG 83

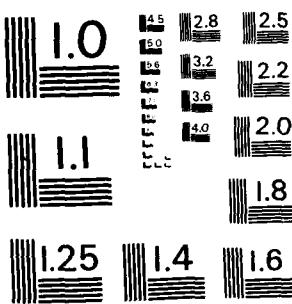
GC-TR-83-286 N00014-82-C-2092

UNCLASSIFIED

F/G 11/6

NL





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS - 1963 - A

12

ADA132364

L

GC-TR-83-286

MEASUREMENT OF FRICTION AND WEAR  
ON MODIFIED SURFACES

DTIC FILE COPY

DTIC  
ELECTE  
S SEP 13 1983 D  
D

GEO-CENTERS, INC.

DISTRIBUTION STATEMENT A  
Approved for public release;  
Distribution Unlimited

83 08 15 007

Accession For	
NTIS GRA&I	
DTIC TAB	
Unannounced	
Justification	
By _____	
Distribution/ _____	
Availability Codes	
Dist	Avail and/or Special
R	



GC-TR-83-286

MEASUREMENT OF FRICTION AND WEAR  
ON MODIFIED SURFACES

PREPARED FOR  
U.S. NAVAL RESEARCH LABORATORY  
4555 OVERLOOK AVENUE  
WASHINGTON, D.C.  
CONTRACT NUMBER N00014-82-C-2092

PREPARED BY  
GEO-CENTERS, INC.  
320 NEEDHAM STREET  
NEWTON UPPER FALLS, MA 02164

AUGUST 1983

DISTRIBUTION STATEMENT A	
Approved for public release	
Distribution Unlimited	

GEO-CENTERS, INC.

## TABLE OF CONTENTS

	<u>Page</u>
Acknowledgments . . . . .	ii
Measurement of Friction and Wear on Modified Surfaces . .	1
Table 1 . . . . .	7
Table 2 . . . . .	8
Figure 1 . . . . .	9
References . . . . .	10

#### ACKNOWLEDGMENTS

We thank the Surface Modification and Analyses Branch of the U.S. Naval Research Laboratory for their support and cooperation with implantation.

## MEASUREMENT OF FRICTION AND WEAR ON MODIFIED SURFACES

Dry sliding friction and wear measurements were used to evaluate two implantation processes which increase the C concentration in Ti-implanted steels. In one process, C is implanted into a Ti-implanted steel; in the second Ti is implanted at a lower energy to enhance the efficiency of the vacuum carburization process. Auger spectroscopy and energy-dispersive X-ray analyses were used to analyze the compositions produced by the implantation processes. The low energy (50 keV/ion) Ti-implantation process produced a low friction ( $\mu=0.3$ ), wear resistant surface at a lower fluence ( $2 \times 10^{17}/\text{cm}^2$ ) than the dual (C+Ti) implantation process at 50 keV/C ion and 190 keV/Ti ion, respectively. The 50 keV Ti-implantation produced more carburization than the 190 keV Ti-implantation itself; but the dual implant had more Ti, more C, and a greater C/Ti ratio than the low energy Ti implant. We concluded that the improved tribological surface of Ti-implanted steel results from vacuum carburization and not just the presence of excess C.

Ion implantation of metals is moving out of the laboratory and into practice as a surface processing technique for improving the wear life of engineering components. While much emphasis has been placed on N-implantation for improving knives, dies and punches subjected to mild abrasive and adhesive wear environments (1-3), Ti-implantation is receiving considerable attention in the bearing and tool steel community (4,5) because of its ability to reduce friction and wear on hardenable steels subjected to severe wear conditions (6-9).

The improved tribological properties of Ti-implanted steels have been attributed to a unique surface alloy produced by high fluence Ti implantation. The alloy is a mixture of Fe-Ti-C (6-10) with a microstructure shown to be amorphous (8,10). The carbon (C), found in excessively high concentrations near the surface, enters the solid from the vacuum chamber, by a process which can be described as implant-assisted vacuum carburization (8,11). During implantation, sputtering erodes the surface and uncovers implanted Ti, which reacts with residual gases in the vacuum chamber, producing surface carbide species. These carbon atoms then migrate inwards, producing the Fe-Ti-C surface alloy. It is not known, however, whether it is the presence of C itself or the process by which C enters the surface that is responsible for creating this remarkable tribological surface. Dual implants of C and Ti have also produced low wear and low friction surfaces (6,12,13).

The purpose of this study is to investigate two different ion implantation processes which increase the carbon concentration in Ti-implanted steels. Dry sliding friction and wear measurements were used to evaluate the processes and compare them to the original high fluence ( $50 \times 10^{16}/\text{cm}^2$ ) high energy (190 keV) process. In one process, separate implantations of Ti and C were performed at energies resulting in similar depth distribution for Ti (190 keV) and C (50 keV) atoms. In the second, Ti was implanted at an energy considerably lower (50 keV) than used previously (190 keV). A recent study of the energy dependence of the Ti implantation process (11) has shown that at lower energies, vacuum carburization is initiated sooner and a more fully carburized layer is produced at a lower fluence. Compositions of surfaces implanted with Ti ions to a fluence of  $2 \times 10^{17}/\text{cm}^2$  will be presented in order to illustrate the effects of the processing methods on the Ti and C distributions.

Steel disks were metallographically polished, then implanted with Ti, Ti and C, or C ions. The disks were carefully heat sunk to prevent heating by the ion beam during implantation ( $T_{\text{Max}} < 50^{\circ}\text{C}$ ). Ti ions were implanted to fluences from 5 to  $50 \times 10^{16}/\text{cm}^2$  at 50 keV or 190 keV, and C ions to  $20 \times 10^{16}/\text{cm}^2$  at 50 keV.

Kinetic friction coefficients ( $\mu_k$ ) were measured under rather severe sliding conditions: low speed (0.1 mm/sec), dry sliding contact in air. The geometry was a 1.27 mm diameter ball sliding against an implanted disk flat (both AISI 52100 steel of hardness  $R_c \sim 60$ ). The ball was loaded to 9.8 N (1 kgf), and up to 20 unidirectional passes were made over the same track. The severity of wear produced during sliding was evaluated by optical (differential interference contrast and interferometry) and electron microscopies.

Table 1 summarizes the friction and wear results for the three implantation processing treatments. Low friction ( $\mu \sim 0.3$ ) values required fluences of  $50 \times 10^{16}/\text{cm}^2$ , except for the low energy (50 keV) implantation process, which gave  $\mu_k = 0.3$  for a fluence of  $20 \times 10^{16}/\text{cm}^2$ . In each of these four low friction surfaces, damage to the "wear" track was negligible. Debris and/or severe wear ( $>50$  nm) was observed on all other tracks (14) except for the Ti+C implant at  $20 \times 10^{16}/\text{cm}^2$ , whose track had a smeared layer but only mild ( $\sim 20$  nm) wear. This dual implanted surface displayed stick-slip in its friction ( $\Delta\mu_k \pm 0.1$ ); moreover, similar friction and wear behavior resulted when the order of implantation was reversed (i.e. C first, then Ti). By way of comparison, nonimplanted and C (alone) implanted disks had high  $\mu_k$  max values, 0.6 and 0.7, respectively, and severely damaged wear tracks. Thus, while C implantation somewhat improved the friction and wear behavior of the Ti implanted to  $20 \times 10^{16}/\text{cm}^2$  at 190 keV, the low energy implant at the same fluence produced a surface as good as the 190 keV Ti implant (with or without C) at  $50 \times 10^{16}/\text{cm}^2$ .

The effects of the three processing treatments on the composition of the implanted surface are revealed in composition vs. depth profiles of the three disks implanted with Ti to  $20 \times 10^{16}/\text{cm}^2$  (i.e. those of column 2 of Table 1). Composition vs. depth profiles were obtained by Auger spectroscopy with ion milling and interferometry; quantitative analysis of Auger data is based on reference compounds (6,8). Figure 1 presents profiles of Ti and excess C (the 4 at.% of C found in the bulk alloy has been subtracted out). The high-energy implant (disk 1) in Figure 1(a) shows a Ti profile which peaks at about 60 nm and a vacuum carburized layer about 50 nm deep. The non-Gaussian shape of the Ti profile indicates that the surface was sputtered during implantation (15). The dual implant (disk 2) in Figure 1(b) shows a similar Ti profile with implanted C and Ti overlapping one-to-one. (The concentration of Ti in disk 2 is about 20% less than in disk 1 because implanted C dilutes the Fe-Ti alloy.) The low-energy implant (disk 3) in Figure 1(c) also shows a sputtered Ti profile, peaked nearer the surface, and a more fully carburized layer than the high-energy implant, disk 1.

The composition profiles shown in Figure 1 are readily explained in terms of implanted ion ranges (16), sputtering (15) and vacuum carburization (11) effects. At low energies, the Ti range profile is shallower and the peak concentration is larger than at high energies. At a fluence of  $20 \times 10^{16}/\text{cm}^2$ , more of the shallow, low-energy Ti implants were removed than the more deeply penetrating high-energy Ti implants by sputtering during the implantation process. (The sputtering rate of steel should be nearly the same at energies of 50 keV and 190 keV (17).) However, carburization occurred sooner with the 50 keV Ti implantation because the Ti atoms reached the surface sooner. Thus, in the low-energy Ti implant, we observed less Ti, a shallower Ti distribution with a higher peak concentration, and a more concentrated carburized layer.

Energy dispersive X-ray analysis (EDX) of Ti in the three disks, presented in Table 2, confirmed that a smaller percentage of Ti was retained by the low-energy implant (disk 3) than in the high-energy implants, disks 2 and 1. Retained Ti doses were also determined by graphical integration of Figure 1 and agree to 15% with the EDX values in Table 2. Doses of incorporated C were also obtained by graphical integration. The C to Ti dose ratios for the three disks are listed in Table 2. It is clear from Figure 1 and Table 2 that the low-energy implant (disk 3) was more carburized than the high-energy implant (disk 1), but had less C, less Ti and smaller C/Ti ratio than the dual implant (disk 2). The low-energy implant also had a larger peak concentration than the high-energy implant (32 at.% vs. 22 at.%); however, previous studies have indicated that Ti without sufficient C has a deleterious effect on friction and wear (8,14). We therefore believe that the larger peak Ti concentration obtained by low energy implantation did not play a significant role in the friction behavior; this, however, needs further investigation.

In summary we have evaluated two ion implantation processes which increase the C concentration in Ti-implanted layers above that of the original treatment. Dry sliding friction and wear studies have demonstrated that a low-energy (50 keV) Ti implant can produce a superior tribological surface than a dual implant (Ti at 190 keV plus C at 50 keV) at a lower fluence. A comparison of the compositions of the implanted layers showed that a 50 keV-implanted surface had a more fully carburized layer than a 190 keV-Ti implanted surface, but less C, less retained Ti, and a smaller C to Ti ratio. It thus appears that the C concentration alone is not a controlling factor in the tribological behavior of the Fe-Ti-C layer. More likely, it is the Fe-Ti-C layer produced during the vacuum carburization process which imparts the tribological improvement.

In conclusion, we have found that a vacuum carburized layer is more effective than implanted carbon in forming a superior tribological surface Ti-implanted steel. The fluence required to produce a fully carburized layer decreases as the energy of the implanted Ti decreases. This result is of great practical importance for the ion implantation processing of materials: lower fluences reduce production time and lower energies cut down beam heating problems. It also suggests that if sequential implants are to be performed at several energies (13), e.g. to produce more uniform composition vs. depth profile, that the lowest energy implants should be done first. Dual implants of C and Ti had a somewhat beneficial effect in a bearing steel. We suggest they may prove even more valuable in softer steels where friction reduction by the Ti-induced carburized layer and solid solution strengthening by the C might combine to improve tribological behavior.

Table 1. Maximum Friction Coefficients and Wear Track Damage  
(n-none; m-mild; s-severe) for Three Ti-Implantation  
Processes as a Function of Ion Energy and Fluence.

Process	Energy (kev)	Fluence ( $\times 10^{16}/\text{cm}^2$ )		
		5	20	50
Low-Energy Ti	50	0.6/s	0.3/n	0.3/n
High-Energy Ti	190	0.8/s	0.8/s	0.3/n
Dual Implant: Ti	190	0.7/s	0.5/m	0.3/n
C	50			

Table 2. Retained Ti Dose and C/Ti Ratio for Three Disks  
Implanted to  $2 \times 10^{17}/\text{cm}^2$ .

	High-Energy Ti Disk 1	Dual Implant Disk 2	Low-Energy Ti Disk 3
Retained Ti $(\pm 1 \times 10^{16}/\text{cm}^2)$ <sup>a</sup>	13	13	9
C/Ti Ratio	0.060	1.0	0.23

a. By EDX, calibrated against a Ti-implanted steel ( $5 \times 10^{16}$  Ti/cm<sup>2</sup> at 190 keV) for which the retention was observed to be almost 100%.

## CONCENTRATION PROFILES OF STEEL IMPLANTED TO $2 \times 10^{17}/\text{cm}^2$

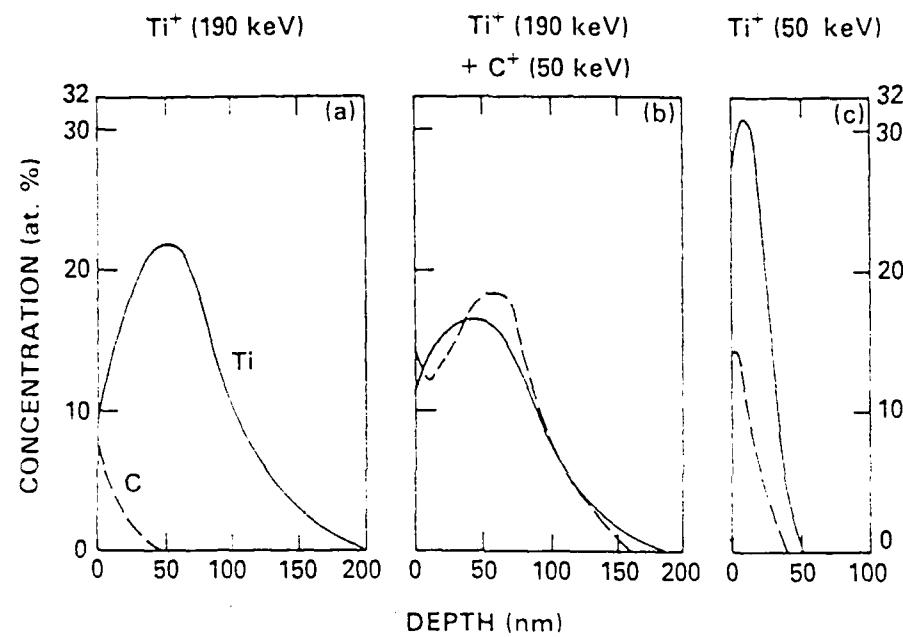


Figure 1. Auger composition vs. depth profiles of Ti and excess C (i.e. above bulk 4 at.%) in 52100 steel implanted to a fluence of  $2 \times 10^{17}/\text{cm}^2$  with (a) disk 1:  $\text{Ti}^+(190 \text{ keV})$ ; (b) disk 2:  $\text{Ti}^+(190 \text{ keV}) + \text{C}^+(50 \text{ keV})$ ; (c) disk 3:  $\text{Ti}^+(50 \text{ keV})$ .

## REFERENCES

1. G. Dearnaley, J. of Metals, 34, 18 (1982).
2. G. Dearnaley, Rad. Effects, 63, 1 (1982).
3. R.E. Fromson and R. Kossowsky, Metastable Materials Formation by Ion Implantation (S.T. Picraux and W.J. Choyke, editors), Elsevier, Amsterdam, 1982, p. 355.
4. F.A. Smidt, J.K. Hirvonen, and S. Ramalingham, NRL Memorandum Report Number 4616, September 25, 1981.
5. Piran Sioshansi (Spire Corporation, Bedford, Massachusetts), reported at Metallurgical Coatings Conference, San Diego, California, April 1983.
6. C.A. Carosella, I.L. Singer, R.C. Bowers, and C.R. Gossett, Ion Implantation Metallurgy (C.M. Preece and J.K. Hirvonen, editors), Metallurgical Society of AIME, Warrendale, Pennsylvania, 1980, p. 103.
7. I.L. Singer, R.N. Bolster, and C.A. Carosella, Thin Solid Films, 73, 283 (1980).
8. I.L. Singer, C.A. Carosella, and J.R. Reed, Nucl. Inst. and Meth., 182/183, 923 (1981).
9. T.E. Fischer, M.J. Luton, J. M. Williams, C.W. White, and B.R. Appleton, ASME/ASLE Lubrication Conference, Washington, D.C., October 1982, ASLE Preprint Number 82-LC-3D-3.
10. J.A. Knapp, D.M. Follstaedt, and S.T. Picraux (C.M. Preece and J.K. Hirvonen, editors), Metallurgical Society of AIME, Warrendale, Pennsylvania, 1980, p. 152; Appl. Phys. Lett., 37, 330 (1980).
11. I.L. Singer, J. Vac. Sci. Technol., A1, 419 (1983).

12. J.K. Hirvonen, C.A. Carosella, R.A. Kant, I.L. Singer, R. Vardiman, and B.B. Rath, Thin Solid Films, 63, 5 (1979).
13. F.G. Yost, L.E. Pope, D.M. Follstaedt, J.A. Knapp, and S.T. Picraux, Metastable Materials Formation by Ion Implantation (S.T. Picraux and W.J. Choyke, editors), Elsevier, Amsterdam, 1982, p. 261.
14. A detailed study of the friction and wear behavior of 190 keV Ti implants is reported in I.L. Singer and R.A. Jeffries, J. Vac. Sci. Technol., A1, 317 (1983).
15. F. Schulz and K. Wittmaack, Rad. Effects, 29, 31 (1976).
16. P.D. Townsend, J.C. Kelly, and N.E.W. Hartley, Ion Implantation, Sputtering and their Applications, Academic Press, New York, 1976, Chapters 2 and 6.
17. The sputtering yield of steel by Ti ions with energies 25 keV to 200 keV should be constant  $S=2.5 \pm 0.5$  if one can extrapolate the yield of Ti from Ar. See H.H. Anderson and H.L. Bay in Sputtering by Particle Bombardment I (R. Behrisch, editor), Springer-Verlag, Berlin, 1981, p. 173.

GEO-CENTERS, INC.  
ANALYSIS OF CONTRACT REVENUES  
FISCAL YEARS 1980, 1981, & 1982

PROJECT NO.	AGENCY	YEAR		
		1980	1981	1982
121	NSWC		\$531	
138	ARRADCOM		\$409	
140	DIA		\$-322	
141	DIA		\$8958	
144	DOE		44	
147	UCONN/DOE		\$10142	\$112
149	USGS		\$788	
152	ARRADCOM		\$45065	
153	ARRADCOM		\$6136	
158	TRPA		\$51394	\$137349
162	JET-L		\$27876	\$55931
163	EGG		\$416	
164	NOSC		\$44926	\$43251
165	CRL		\$47086	\$32796
166	NRC		\$11774	\$1561
167			\$20858	
168	DOE	170358	\$77534	\$490228
169	INTEL		\$73431	\$-116
171	NRC		\$8057	\$83431
173	NEC/L-DOE		\$13112	\$13497
176	USGS		\$17694	\$63574
180	NEL		\$11016	\$114797
182	NEL		\$44770	\$85938
183	ARRADCOM			\$3089
184	NEL		\$24601	\$62084
185	Patterson-Hobson NEL		\$28066	\$143428
187	ARRADCOM		\$495	\$48088
188	INTEL		\$16002	\$77394
192	TMI		\$37355	\$8104
193	NEC/L		\$9988	\$75676
195	TMI		\$4450	\$2231
200	EGG		\$5046	\$-5
201	TMI		\$3494	\$19143
202	LKT - Pacific Island		\$23238	
204			\$8608	
209	INTEL		18265	
212	TMI		3089	\$89405
217				
218			19246	
219	NOS		48510	
220			\$22045	\$1051
224			\$45430	\$67193
225	Al Ridge			\$42H40
228	EGG		\$31594	
229			\$34960	
230	EGG		\$48048	\$41517
232	EGG		\$14806	
235	TMI		3072	
242	DIA		2000	
244	NRL		\$1972	\$36646
246	American Samoa		\$8486	\$514
			\$21825	

251 Detalle	\$909
255 M&F Dec	\$50138
256 File Dec	\$49431
258 INEL	\$308
260 NEL	\$16846
261 NEL	\$30437
262 JNEL	\$1000
263 NEL	\$4422
264 INEL	\$9600
266 NEL Cen	\$18352
267 JNEL	\$14503
268 Lab A..	\$82418
269 NRL.	\$20532
270 JNEL	\$20000
272 NRL - E 5	\$65700
273 DPPA	\$23653
281 NEL Lihlba	\$68432
282	\$14696
286 NEL - F 4	\$40811
287 NPPC	\$246
288 NEL - Lihlba	\$61519
289 FG6	\$15341
291 NL	\$9511
292 FG6	\$8375
293 EG6	\$109227
295 EG6	\$2375
298 EG16 - 100	\$33697
299 Base pay	\$75116
302 FG6	\$5000
320 NEL	\$32040
323 Dan Peter	\$35726
331 FG6	\$1701
332 EG6	\$8685
336 NEL	\$20000
337 NEL	\$15000
338 DPPA	\$20416
339 EG6	\$41687
341 GTE - Submar	\$9758
347	\$4730
356 FG6	\$3067
362 EGEG	\$3065
363 INEL	\$3671
999 = m 14	\$1967
	\$12450
	\$7517
TOTALS	\$649942
	\$1741334
	\$2219827
Est. E.G. 6	=====

END  
DATE  
FILMED

9 - 83

DT